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VENUS AND MARS NOMINAL NATURAL ENVIRONMENT FOR ADVANCED MANNED PLANETARY MISSION PROGRAMS

EVANS, PITTS, and KRAUS

SECOND EDITION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SECOND EDITION

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Preface

The data in this revised edition differ from those given in the first edition mainly as a result of the Mariner IV Mars flyby experimental results. The meteoroid flux environment is not quite as severe as previously predicted, and there are no significant changes in the solar flare charged-particle environment except the inclusion of an alpha particle flux statement. However, the surface atmosphere pressure of Mars has been revised downward considerably along with other changes throughout the Mars environment.

There have not been any changes made to the data for the Venus environment; however, modifications are presently being considered for forthcoming revisions.

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1.0 Introduction

1.1 Purpose

The purpose of this document is to establish numerical values for a nominal natural environment for application in studies for advanced manned planetary missions to Venus and Mars.

Compilation of the data in this document is to provide a standard environment so that various mission and preliminary design studies will all be based on realistic data and have a common basis for comparison of end results.

1.2 Scope

It is not anticipated that real hardware design would be based on this nominal environment, but with periodic revision as new data become available, this document would be sufficiently accurate and up-to-date to serve as a hardware design environment when the need becomes apparent.

It must be realized that large uncertainties exist in many of the environmental parameters, but in those cases, where possible, "present best estimate" plus extreme lower and upper limit values are presented.

The data for the natural environment have been broken into several sections to account for a wide variety of environmental factors which may be needed for study requirements. Appropriate references are given for the various literature sources from which the information was obtained. In those cases where references are not given, the data were generated at the Manned Spacecraft Center.

2.0 Interplanetary Space

Interplanetary space is defined as the spatial volume between the planets extending from the Sun to the outer limit of the solar system. This section primarily concerns environmental parameters for interplanetary space from 0.5 to 1.75 astronomical units (A.U.).

2.1 Meteoroid Environment

2.1.1 Model.- Flux-mass relation (unshielded):

Cometary (sporadic and stream) and zodiacal light particles from 0.5 to 3.5 A.U.:

$$\text{Log}_{10}(N > m) = -1.34 \log_{10} m - 14.29 - \log_{10} R$$

where:

$$m \geq 10^{-2.19} \text{ gm}$$

$$\text{Log}_{10}(N > m) = -\log_{10} m - 13.56 - \log_{10} R$$

where:

$$m \leq 10^{-2.19} \text{ gm}$$

Flux never exceeds:

$$\text{Log}_{10}(N > m) = -0.30 \log_{10} m - 7.96 - 2.0 \log_{10} R$$

Average density: 0.50 gm/cm^3

Average relative velocity (V_c): $V_c = 20\ R^{-1/2}$ km/sec

The average relative velocity given is for a spacecraft in direct circular orbit at a distance R from the Sun. The relative velocity will vary depending upon the spacecraft orbit.

Asteroidal particles:

$$\text{Log}_{10}(N > m) = -\log_{10} m - 17.53 + 3.0\ R$$

where:

$$R \leq 2.6$$

$$\mathrm{Log}_{10}(N > m) = -\log_{10} m - 9.73$$

where:

$$2.6 \leq R \leq 3.5$$

Asteroidal flux never exceeds:

$$\mathrm{Log}_{10}(N > m) = -2/3 \log_{10} m - 11.08 - \log(1/R - 1/3.5)$$

where:

$$R < 3.5$$

Average density: 3.5 gm/cm^3

Average relative velocity: $V_a = 15R^{-1/2}$ km/sec

where:

N = number/m^2-sec
m = mass, grams
R = solar distance, A.U.

Zero-magnitude meteor mass: 1.0 gram ($V = 30$ km/sec)

2.1.2 Erosion rate.- Since definite data are lacking in this area, the following may be assumed as average values from 0.5 to 1.75 A.U.:

Depth rate of meteoritic erosion (for Al or Mg): 1.5×10^{-13} cm/sec

Corpuscular sputtering (for Al or Mg): 2×10^{-13} gm/cm^2-sec

Material sublimation (for Al or Mg): $\approx 10^{-13}$ gm/cm^2-sec

2.2 Radiation Environment

2.2.1 Galactic cosmic radiation (refs. 1 to 4).-

Composition: $\approx$ 85% protons (H^+)
$\approx$ 14% alpha particles (He^{++})
$\approx$ 1% nuclei of elements Li→Fe in approximate cosmic abundance

Flux at sunspot minimum:

4 particles/cm^2-sec (isotropic)

Integrated yearly rates:

1.2×10^8 particles/cm^2

Flux at sunspot maximum:

1.5 particles/cm^2-sec (isotropic)

Integrated yearly rates:

5×10^7 particles/cm^2

Energy range:

$\approx$ 100 MeV to 10^{19} eV
predominate energy 10^9 to 10^{13} eV

Integrated dosage:

6 to 20 rads/yr
$\approx$ 0.6 to $\approx$ 2.2 millirads/hr

2.2.2 <u>Solar high energy particle radiation</u>.-

Composition:

Consists of protons (H^+) and alpha particles. The ratio of protons to alpha particles depends upon solar activity. An average ratio of 1:1 may be assumed.

Integrated yearly flux:

solar maximum - energy > 30 MeV = 3.5×10^9 particles/cm^2
energy > 100 MeV = 3×10^8 particles/cm^2
solar minimum - total 10^6 particles/cm^2

Average dosage with shielding of 5 gm/cm^2:

75 rem/yr at maximum
< 1 rem/yr at minimum

This radiation environment applies for a solar distance of 1.0 A.U. The dispersion processes acting upon this environmental parameter have not been defined as yet; and, therefore, do not allow an accurate description of the radiation environment to be given for solar distances near 0.5 A.U. and 1.75 A.U.

2.2.3 Solar flares.-

2.2.3.1 Probability of encountering solar flare protons: For the probability (p) of encountering more than N protons/cm^2 with rigidity (P) greater than 0.235 Bv for various mission lengths, refer to the following table. Although the rate of change of the number of protons/cm^2 with solar distance is unknown, the tabulated values may be used for 0.5 to 1.75 A.U. with an accuracy of perhaps one order of magnitude.

Mission length, weeks	Probability, p			
	0.50	0.10	0.01	0.001
	N, protons/cm^2			
2	-	5.0×10^{7}	2.0×10^{9}	1.7×10^{10}
4	-	2.0×10^{8}	4.5×10^{9}	3.3×10^{10}
8	1.3×10^{7}	7.2×10^{8}	9.0×10^{9}	5.6×10^{10}
12	4.5×10^{7}	1.3×10^{9}	1.5×10^{10}	8.0×10^{10}
20	1.5×10^{8}	2.4×10^{9}	2.2×10^{10}	1.1×10^{11}
30	3.0×10^{8}	3.9×10^{9}	3.0×10^{10}	1.4×10^{11}
40	5.0×10^{8}	5.0×10^{9}	3.3×10^{10}	1.5×10^{11}
50	7.0×10^{8}	5.9×10^{9}	3.5×10^{10}	1.6×10^{11}
60	1.0×10^{9}	6.2×10^{9}	3.7×10^{10}	1.6×10^{11}
80	1.6×10^{9}	7.2×10^{9}	3.9×10^{10}	1.7×10^{11}
100	2.0×10^{9}	8.0×10^{9}	4.0×10^{10}	1.7×10^{11}

2.2.3.2 Model time integrated spectral distribution:

$$N\ (> P) = N_o \exp\left(-\frac{P}{P_o}\right)$$

where:

N = protons/cm^2 having rigidity greater than P
P = rigidity, or momentum per unit charge, in volts
P_o = 97 MeV, a value typical for large events
N_o = total intensity of event (particles/cm^2)

$$P = \frac{1}{eZ}\left(T^2 + 2Tm_oc^2\right)^{1/2}$$

where:

eZ = nuclear charge
T = proton energy, (MeV)
m_oc^2 = proton rest energy = 938.2 MeV for protons
3727.1 MeV for alpha particles

P_o is evaluated for energies $T \geq 10$ MeV. Below 10 MeV, the spectrum may be described by the expression: $N(> T) \simeq N_oT^{-n}$, with n approximately equal to 1.2.

A model spectrum is described by the following expressions:

$T < 10$ MeV : $N(> T) = 72.8N(> 239 \text{ Mv})T^{-1.2}$
$137 \text{ Mv} < P < 239$ Mv: $N(> P) = 35.5N(> 239 \text{ Mv})e^{-P/67}$
$P \geq 239$ Mv : $N(> P) = 10.9N(> 239 \text{ Mv})e^{-P/100}$

2.3 Gas Properties

2.3.1 Gas pressure (ref. 5).- Gas pressure varies with solar activity and probably follows a $1/R^2$ dependence. Pressure at quiet solar conditions is $< 10^{-10}$ dyne/cm^2 at 1.0 A.U.

2.3.2 Gas density (ref. 5).- Gas density varies with solar activity and probably follows a $1/R^2$ dependence. A density of $< 10^{-18}$ gm/cm^3 may be taken as an average value at 1.0 A.U. The composition is primarily H and H^+ with a trace of He.

2.3.3 Kinetic gas temperature (refs. 5, 6, and 7).- At 1.0 A.U., the kinetic gas temperature is about $2 \times 10^{5°}$ K. The mean free path of gas particles is about 10^7 km. The kinetic gas temperature decreases with increasing solar distance in a manner such that the temperature difference from 0.5 to 1.75 A.U. is about $10^{5°}$ K. The spatial heat sink is that of a radiant energy reservoir with an effective radiating temperature of 4° to 6° K in all directions, which does not intercept volumes occupied by the Sun or planets.

2.4 Magnetic Fields (Refs. 8 to 10)

The principal magnetic field in the space from 0.5 to 1.75 A.U. (solar distance) is that of the Sun as carried by the solar plasmas. The strength of the solar interplanetary magnetic field may range from 0 to 100 gammas at 1.0 A.U., averaging about 4 or 5 gammas. The strength of the field depends upon solar activity, with maximum field strength at maximum solar activity. Mariner II indicated an increase to 10 gammas upon nearing the orbit of Venus. Mariner IV data indicate a strongly disordered interplanetary magnetic field out to the orbit of Mars; an average value $\approx$ 3 gammas may be assumed. Fluctuations of one or two orders of magnitude may occur, depending upon solar activity.

2.5 Radiation Properties of the Sun (Thermal)

2.5.1 Solar radiation (refs. 11 and 12).-

Solar constant at 1.0 A.U.:

1400 watts/m^2

2.00 cal/cm^2/min

Variation with distance from Sun follows R^{-2} relation, e.g.,

$$\text{Solar constant in space} = \text{solar constant at 1 A.U.}/R^2$$

where:

R = distance from Sun, A.U.

Variation of Solar Constant with Solar Distance			
Solar distance, A.U.	Solar constant, watts/m^2	Solar distance, A.U.	Solar constant, watts/m^2
0.5	5600	1.2	972
0.6	3889	1.3	828
0.7	2857	1.4	714
0.8	2187	1.5	622
0.9	1728	1.6	547
1.0	1400	1.7	484
1.1	1157	1.75	457

Light flux at 1.0 A.U.:

13.7 lumens/cm^2
12 728 foot-candles
variation with solar distance follows
R^{-2} relation, e.g.,

$$\text{Light flux in space} = \text{light flux at 1.0 A.U.}/R^2$$

where:

R = distance from Sun, A.U.

2.5.1.1 Visible and infrared radiation (ref. 13):

Radiant energy distribution:

approximated by that from a 6000° K black body

Fraction of solar radiation:

above 7000 Å = 52%
above 4000 Å = 93%

2.5.1.2 Ultraviolet and X-ray radiation (refs. 5, 11, and 13):

Fraction of solar radiation:

below 4000 Å = 7%
below 3000 Å = 1%

below 2000 Å = 0.02%
below 1000 Å = 10^{-4}%

Principal line emission fluxes at 1.0 A.U.:

Lyman Alpha H I (1216 Å), 60×10^{-8} watt/cm^2
He II (304 Å), 3×10^{-8} watt/cm^2
H I (1026 Å), 2×10^{-8} watt/cm^2
C III (977 Å), 2×10^{-8} watt/cm^2
Si II (1817 Å 2×10^{-8} watt/cm^2

X-ray flux:

20 to 100 Å region, 6×10^{-8} watt/cm^2
8 to 20 Å region, 2×10^{-10} watt/cm^2
2 to 8 Å region, 5.5×10^{-11} watt/cm^2

X-ray flux variation: During periods of solar activity, variations in the X-ray flux on the order of one or two magnitude increases may occur.

Strength of line emission flux varies as R^{-2}, e.g.,

$$\text{Flux in space} = \text{flux at 1.0 A.U.}/R^2$$

where:

R = solar distance, A.U.

2.5.1.3 Solar radiation pressure (ref. 14):

Pressure at 1.0 A.U.:

for 100% reflecting body = 9×10^{-5} dyne/cm^2
for black body = 4.5×10^{-5} dyne/cm^2

Radiation pressure variation with solar distance follows the relation:

$$P_r = S/c \text{ for black body}$$
$$P_r = 2S/c \text{ for 100\% reflecting body}$$

where:

P_r = radiation pressure
S = solar constant at specified solar distance
c = speed of light

2.5.1.4 Solar wind (ref. 9):

Average density:

0.5 A.U. ≈ 20 hydrogen atoms/cc
1.0 A.U. ≈ 5 hydrogen atoms/cc
1.75 A.U. ≈ 2 hydrogen atoms/cc

Average flux:

0.5 A.U. ≈ 8×10^8 hydrogen atoms/cm^2/sec
1.0 A.U. ≈ 2×10^8 hydrogen atoms/cm^2/sec
1.75 A.U. ≈ 10^8 hydrogen atoms/cm^2/sec

Average velocity of solar wind:

from 0.5 A.U. to 1.75 A.U. = 450 to 500 km/sec

2.6 Solar Radio Noise (Ref. 13)

$$\text{Noise power flux} = \frac{\left(4.5 \times 10^{-31}\right)(f)^{1.1}}{R^2} \text{ watts/m}^2\text{/cps}$$

where:

f = frequency, cycles/sec (cps)
R = distance from Sun, A.U.

Approximate noise power at 1.0 A.U., quiet Sun:

10^{-19} watt/m^2/cps at 1.0 cm wavelength to
10^{-22} watt/m^2/cps at 400 cm wavelength

During solar storms, noise power may increase 1 to 8 orders of magnitude. The variation with sunspots is greatest between wavelengths of 6 to 200 cm, with the spectral power showing a range of variation of 4 orders of magnitude.

3.0 Near-Venus Space

Near-Venus space is defined as the region between 180 km and 20 000 km above the surface of Venus.

3.1 Meteoroid Environment

3.1.1 Model.- See paragraph 2.1.1.

3.1.2 Erosion rate.- See paragraph 2.1.2.

3.2 Radiation Environment

3.2.1 Galactic cosmic radiation.- See paragraph 2.2.1.

3.2.2 Solar high energy particle radiation.- See paragraph 2.2.2. Some enhancement of this radiation environment will probably occur at the orbit of Venus.

3.2.3 Solar flares.- See paragraph 2.2.3.

3.3 Gas Properties

The following gas properties of near-Venus space were calculated on a theoretical basis in the determination of the mean Venus model atmosphere. Because of uncertainties in the atmospheric parameters, some variation in the values may occur.

3.3.1 Gas pressure.- Gas pressure ranges from 10^{-2} dyne/cm^2 at 180 km altitude to that of nearby space of 10^{-10} dyne/cm^2. Refer to the table in 3.3.3.

3.3.2 Gas density.- Gas density ranges from 10^{-11} gm/cc at 180 km to that of nearby space 10^{-18} gm/cc. Composition is primarily ionized gases of the decomposition products of the Venus atmosphere. Refer to the table in 3.3.3

3.3.3 Kinetic gas temperature.- The kinetic gas temperature is 373° K at 180 km altitude and will probably increase with increasing altitude until merging with the interplanetary gas which is at a kinetic temperature of 2.4×10^5° K. Refer to the following table.

Gas Properties of the Venus Atmosphere			
Altitude, km	Pressure, dyne/cm^2	Density, gm/cc	Temperature, °K
180	1.49×10^{-2}	1.54×10^{-11}	372.6
250	1.02×10^{-4}	7.39×10^{-14}	528.9
300	6.99×10^{-6}	4.20×10^{-15}	640.5
350	7.22×10^{-7}	4.36×10^{-16}	752.2
400	1.63×10^{-7}	9.85×10^{-17}	863.8
500	2.25×10^{-8}	1.36×10^{-17}	1087.1
600	6.6×10^{-9}	3.98×10^{-18}	1310.4
800	1.65×10^{-9}	9.98×10^{-19}	1757.0
1000	8.18×10^{-10}	4.94×10^{-19}	2203.6
Interplanetary	$< 10^{-10}$	$\approx 10^{-22}$	$\approx 2.4 \times 10^5$

3.4 Magnetic Fields (Ref. 8)

Planetary: Mariner II data indicate a planetary magnetic field considerably less than that of the Earth's.

Solar: Estimates place the average magnetic field at about 10 gammas but varying constantly, depending on solar activity.

3.5 Radiation Properties of the Sun and Venus

3.5.1 Solar radiation.- See paragraph 2.5.1.

3.5.1.1 Visible and infrared radiation: See paragraph 2.5.1.1.

3.5.1.2 Ultraviolet and X-ray radiation: See paragraph 2.5.1.2.

3.5.1.3 Solar radiation pressure: See paragraph 2.5.1.3.

3.5.1.4 Solar wind: See paragraph 2.5.1.4.

3.5.2 Planetary radiation.- The total radiation from Venus consists of the sum of thermal and albedo radiation from Venus and decreases with the distance from the surface of Venus and position angle measured from the Venus-Sun line.

3.5.2.1 Thermal radiation (ref. 15): Thermal radiation varies from ≈ 238 watts/m^2 at 200 km to ≈ 9 watts/m^2 at $\approx 2 \times 10^4$ km. Dark side radiation is same as above, although flux is subject to question because of the uncertainty in planet atmosphere and surface temperatures. Thermal radiation will consist predominantly of radiation from ≈ 2 to 10 microns wavelength.

The thermal radiation flux may be found from the general equation:

$$Q = FAI$$

where:

Q = thermal radiation flux upon vehicle
F = view factor (varies with altitude above the planet and vehicle shape)
A = cross sectional area of exposed spherical surface
I = planetary thermal radiation flux

Refer to the table in 3.5.2.2.

3.5.2.2 Albedo radiation (ref. 15): Albedo radiation varies from $\approx 3 \times 10^3$ watts/m^2 at ≈ 200 km to ≈ 90 watts/m^2 at $\approx 2 \times 10^4$ km under maximum conditions (zero phase angle and normal to flux). Spectral distribution of albedo radiation is expected to approximate the solar spectrum. Albedo radiation will contribute ≈ 90 percent of total radiation from planet upon spacecraft.

No reliable determinations of the integrated albedo of Venus are available at present. Therefore, values appearing in this section were based upon the assumption that the integrated albedo is approximated by the visual albedo. The albedo radiation flux may be found from the general equation:

$$Q = FASa$$

Where:

Q = albedo radiation flux upon vehicle
F = view factor
A = cross sectional area of exposed spherical surface
S = solar constant at the planet
a = planetary albedo

Refer to the following table.

Venus Thermal and Albedo Radiation Upon A Spherical Satellite		
Albedo = 0.76 solar constant = 2670 watts/m^2, Thermal radiation flux = 160 watts/m^2.		
Altitude, km	Thermal, watts/m^2	Albedo, watts/m^2
200	238	3 000
400	208	2 660
600	189	2 400
1 000	152	1 920
4 000	67	770
8 000	35	354
20 000	9	89

3.5.2.3 Planetary albedo (ref. 16): The visual albedo of Venus is 0.76.

3.5.3 Planetary radiation belts (ref. 8).- No definite data are available to date. However, the apparently small magnetic field of Venus would seem to preclude the existence of any significant radiation belts about the planet as compared to Earth.

3.6 Solar Radio Noise (Ref. 13)

See paragraph 2.6. The solar radio noise may be expected to increase about 90 percent from Earth to Venus.

4.0 Venus Atmosphere and Surface Conditions

The atmosphere of Venus is defined as the region between the surface level and 200 km $\left(10^{-11}\ \text{gm/cm}^3\right)$.

4.1 Atmospheric Molecular Weight and Composition (Ref. 17)

4.1.1 Molecular weight.-

Maximum	Mean	Minimum
40.0	32.0	29.6

4.1.2 Composition by volume percentage.-

	Maximum	Mean	Minimum
CO_2	75	25	10
N_2	90	75	20
O_2	1	small	0
H_2O (mm)	2.5	1.5	0.1

4.2 Model Atmosphere Structure

Three model atmospheres are presented in describing the structure of the Venus atmosphere. The values given are tabulated in terms of the particular model (upper, mean, and lower density models) and in terms of the maximum, mean, and minimum values for the quantities of interest. Thus, a consistent set of quantities for any one of the three model atmospheres may be obtained from the tables by following the "model" nomenclature, while the variation in a given quantity may be obtained by following the headings "maximum", "mean", and "minimum".

The parameters used for construction of these model atmospheres are given in paragraphs 4.1 and 4.14.

4.2.1 Atmospheric pressure.-

Z, km	Upper density model, max., mb	Mean density model, mean, mb	Lower density model, min., mb
0	4.05×10^{4}	1.01×10^{4}	5.07×10^{3}
5	3.31×10^{4}	7.88×10^{3}	3.57×10^{3}
10	2.67×10^{4}	6.04×10^{3}	2.46×10^{3}
20	1.68×10^{4}	3.36×10^{3}	1.06×10^{3}
30	9.94×10^{3}	1.69×10^{3}	3.84×10^{2}
40	5.40×10^{3}	7.40×10^{2}	1.05×10^{2}
50	2.61×10^{3}	2.59×10^{2}	1.74×10^{1}
75	1.50×10^{2}	6.98	1.42×10^{-1}
100	3.67	1.77×10^{-1}	1.65×10^{-3}
150	3.56×10^{-3}	2.63×10^{-4}	3.33×10^{-6}
200	2.75×10^{-5}	2.94×10^{-6}	4.66×10^{-8}
300	4.60×10^{-8}	6.99×10^{-9}	1.38×10^{-10}
400	6.53×10^{-10}	1.18×10^{-10}	2.59×10^{-12}

4.2.2 Atmospheric temperature.-

Z, km	Upper density model, max., °K	Mean density model, mean, °K	Lower density model, min., °K
0	750.0	700.0	650.0
5	712.6	659.7	608.0
10	674.8	619.0	565.2
20	598.3	536.4	477.1
30	520.7	452.1	384.7
40	442.1	366.1	286.6
50	362.7	278.6	224.0
75	194.2	225.2	224.0
100	194.2	225.2	273.0
150	242.6	305.6	417.4
200	339.4	417.3	561.7
300	533.0	640.5	850.3
400	726.6	863.8	1139.0

4.2.3 Atmospheric density.-

Z, km	Upper density model, max., gm/cm^3	Mean density model, mean, gm/cm^3	Lower density model, min., gm/cm^3
0	1.92×10^{-2}	5.57×10^{-3}	3.75×10^{-3}
5	1.65×10^{-2}	4.60×10^{-3}	2.83×10^{-3}
10	1.41×10^{-2}	3.76×10^{-3}	2.09×10^{-3}
20	1.00×10^{-2}	2.41×10^{-3}	1.07×10^{-3}
30	6.80×10^{-3}	1.44×10^{-3}	4.81×10^{-4}
40	4.35×10^{-3}	7.78×10^{-4}	1.76×10^{-4}
50	2.56×10^{-3}	3.59×10^{-4}	3.73×10^{-5}
75	2.75×10^{-4}	1.19×10^{-5}	3.05×10^{-7}
100	6.73×10^{-6}	3.02×10^{-7}	2.90×10^{-9}
150	5.22×10^{-9}	3.31×10^{-10}	3.84×10^{-12}
200	2.88×10^{-11}	2.71×10^{-12}	3.99×10^{-14}
300	3.07×10^{-14}	4.20×10^{-15}	7.78×10^{-17}
400	3.20×10^{-16}	5.25×10^{-17}	1.09×10^{-18}

4.2.4 Atmospheric mean free path.-

Z, km	Lower density model, max., cm	Mean density model, mean, cm	Upper density model, min., cm
0	2.9×10^{-6}	1.6×10^{-6}	4.5×10^{-7}
5	3.5×10^{-6}	1.9×10^{-6}	4.9×10^{-7}
10	4.7×10^{-6}	2.3×10^{-6}	5.7×10^{-7}
20	9.3×10^{-6}	3.5×10^{-6}	8.0×10^{-7}
30	2.1×10^{-5}	5.9×10^{-6}	1.2×10^{-6}
40	5.6×10^{-5}	1.1×10^{-5}	1.8×10^{-6}
50	2.7×10^{-4}	2.4×10^{-5}	3.1×10^{-6}
75	3.2×10^{-2}	7.1×10^{-4}	2.9×10^{-5}
100	3.4	2.8×10^{-2}	1.2×10^{-3}
150	2.6×10^{3}	2.6×10^{1}	1.5
200	2.5×10^{5}	3.1×10^{3}	2.8×10^{2}
300	1.3×10^{8}	2.0×10^{6}	2.6×10^{5}
400	9.1×10^{9}	1.6×10^{8}	2.5×10^{7}

4.2.5 Coefficient of viscosity.-

Z, km	Upper density model, max., kg/m-sec	Mean density model, mean, kg/m-sec	Lower density model, min., kg/m-sec
0	3.42×10^{-5}	3.19×10^{-5}	2.88×10^{-5}
5	3.27×10^{-5}	3.03×10^{-5}	2.70×10^{-5}
10	3.12×10^{-5}	2.87×10^{-5}	2.52×10^{-5}
20	2.83×10^{-5}	2.54×10^{-5}	2.17×10^{-5}
30	2.53×10^{-5}	2.22×10^{-5}	1.82×10^{-5}
40	2.24×10^{-5}	1.90×10^{-5}	1.46×10^{-5}
50	1.95×10^{-5}	1.58×10^{-5}	1.23×10^{-5}
75	1.30×10^{-5}	1.38×10^{-5}	1.23×10^{-5}
100	1.30×10^{-5}	1.38×10^{-5}	1.41×10^{-5}
150	1.49×10^{-5}	1.68×10^{-5}	1.94×10^{-5}
200	1.86×10^{-5}	2.09×10^{-5}	2.51×10^{-5}
300	2.58×10^{-5}	2.95×10^{-5}	3.82×10^{-5}
400	3.33×10^{-5}	3.90×10^{-5}	5.46×10^{-5}

4.2.6 Atmospheric pressure scale height.-

Z, km	Upper density model, max., km	Mean density model, mean, km	Lower density model, min., km
0	25.31	20.53	14.78
5	24.08	19.38	13.85
10	22.84	18.21	12.90
20	20.32	15.83	10.92
30	17.74	13.39	8.84
40	15.11	10.88	6.61
50	12.44	8.31	5.18
75	6.71	6.77	5.22
100	6.77	6.83	6.42
150	8.59	9.41	9.98
200	12.20	13.06	13.65
300	19.76	20.70	21.34
400	27.77	28.80	29.50

4.2.7 Atmospheric speed of sound.-

Z, km	Upper density model, max., m/sec	Mean density model, mean, m/sec	Lower density model, min., m/sec
0	543	505	435
5	529	490	421
10	515	475	406
20	485	442	373
30	452	406	335
40	417	365	289
50	378	318	255
75	276	286	255
100	276	286	282
150	309	333	348
200	365	390	404
300	458	483	497
400	535	561	576

4.2.8 Atmospheric number density.-

Z, km	Upper density model, max., cm^{-3}	Mean density model, mean, cm^{-3}	Lower density model, min., cm^{-3}
0	3.9×10^{20}	1.3×10^{20}	5.6×10^{19}
5	3.4×10^{20}	8.7×10^{19}	4.3×10^{19}
10	2.9×10^{20}	7.1×10^{19}	3.1×10^{19}
20	2.0×10^{20}	4.5×10^{19}	1.6×10^{19}
30	1.4×10^{20}	2.7×10^{19}	7.2×10^{18}
40	8.9×10^{19}	1.5×10^{19}	2.6×10^{18}
50	5.2×10^{19}	6.7×10^{18}	5.6×10^{17}
75	5.6×10^{18}	2.2×10^{17}	4.6×10^{15}
100	1.4×10^{17}	5.7×10^{15}	4.4×10^{13}
150	1.1×10^{14}	6.2×10^{12}	5.8×10^{10}
200	5.9×10^{11}	5.1×10^{10}	6.0×10^{8}
300	6.3×10^{8}	7.9×10^{7}	1.2×10^{6}
400	6.5×10^{6}	9.9×10^{5}	1.6×10^{4}

4.2.9 Atmospheric density scale height.-

Z, km	Upper density model, max., km	Mean density model, mean, km	Lower density model, min., km
0	33.81	26.83	18.43
5	32.28	25.42	17.16
10	30.73	23.98	16.05
20	27.52	21.01	13.75
30	24.17	17.90	11.29
40	20.70	14.65	8.62
50	17.11	11.27	5.18
75	6.71	6.77	5.22
100	6.77	6.83	6.01
150	8.04	8.81	9.33
200	11.41	12.21	12.75
300	18.44	19.30	19.89
400	25.86	26.80	27.45

4.2.10 Atmospheric columnar mass above a given altitude.-

Z, km	Upper density model, max., gm/cm^2	Mean density model, mean, gm/cm^2	Lower density model, min., gm/cm^2
0	49 000	11 500	5 560
5	40 100	8 960	3 920
10	32 400	6 880	2 700
20	20 400	3 830	1 170
30	12 100	1 940	420
40	6 600	900	110
50	3 200	300	10
75	200	0.	0.
100	0.	0.	0.

4.2.10.1 Columnar mass for Earth above a given altitude:

Z, km	Mass, gm/cm^2
0	1033.6
5	629.6
10	314.6
15	144.6
20	66.6
25	34.6
30	14.6
35	4.6

4.3 Atmospheric Winds for Venus

High surface winds are expected; they may be heavily dust-laden.

4.4 Wind Shear

No data.

4.5 Clouds in the Atmosphere (Refs. 8, 18, and 19)

4.5.1 Composition.- Estimates from various atmospheric models include water vapor, ice crystals, dust, carbon suboxide polymers, or suspended hydrocarbons.

4.5.2 Height of the clouds.- The top of the clouds is from 30 km to 65 km above the surface of the planet.

4.5.3 Depth of the clouds.- The depth of the clouds is approximately 10 to 15 km.

4.6 Micrometeoroid Environment

See paragraph 1.2 with the addition of the following:

4.6.1 Survival mass.- The survival mass for micrometeoroids can be calculated as a function of height in the atmosphere by using the following approximate expression:

$$m_\infty^{1/3} = \frac{\Lambda A \rho_m^{-2/3} V^2}{\xi \, 6 \cos Z} \int_{-\infty}^{h} \rho_a \, dh$$

where:

$$\text{columnar mass (par. 4.2.10)} = \int_{-\infty}^{h} \rho_a \, dh$$

Z = zenith angle

ρ_m = density of micrometeroid $\left(3.5 > \rho_m > 0.5 \text{ gm/cm}^3\right)$

V = velocity of micrometeoroid $\left(V_{parabolic} + V_{orbital} > V > V_{escape}\right)$

A = shape factor = 1.2 for sphere

$\frac{\Lambda}{\xi} = 2 \times 10^{-11.75}$

4.7 Magnetic Field of Venus (Ref. 8)

Mariner II indicates a planetary magnetic field considerably less than that of the Earth. Measurements of the rotational speed of Venus are consistent with this observation, since very weak magnetic fields would be produced by speeds of rotation of 1 week to 225 days (Venus might even have retrograde rotation).

4.8 Atmospheric Circulation (Ref. 20)

The slow rotational speed will cause the atmospheric fluid to rise near the sub-solar point and subside near the antisolar point in a symmetrical regime. However, at higher altitudes, a symmetric regime similar to that of a rotating planet may be predominate (i.e., where ascent occurs near the equator and descent occurs near the poles).

4.9 Ionosphere (Ref. 8)

Although undetected by Mariner II, an ionosphere may be assumed to be present. It will differ from the Earth's by having little or no free oxygen.

4.10 Albedo

See paragraph 3.5.2.3.

4.11 Surface Features, Terrain, and Composition of the Surface (Refs. 18 and 20)

4.11.1 Surface features.- No breaks large enough to see the surface have ever been seen in the clouds, so no observational data exist. However, Mariner II detected a large region slightly cooler than the rest of the disc, which possibly represents the influence of a surface feature.

4.11.2 Terrain and composition of the surface.- Though the surface has never been seen, it is generally agreed that it is probably dry, dusty, rocky, and windy. One of the explanations of the high surface temperature on the dark side of Venus is that the surface has a very high specific heat capacity. This has led to the conjecture that the surface consists of a layer of liquid hydrocarbons or a layer of hydrocarbons floating on an ocean of water. However, with surface temperatures near 700° K the surface is probably dry and dusty.

4.12 Planetary Satellites

No satellites have been detected.

4.13 Surface Temperatures (Refs. 8, 17, and 18)

Measurements from the Earth indicate a surface temperature of about 600° K to 650° K. Mariner II yielded 700° K. The actual temperature is very likely 700° ± 50° K.

4.14 Construction Parameters for the Model Atmospheres (Refs. 6, 14, 15, 18, and 21)

Quantity	Upper density model	Mean density model	Lower density model
Radius,			
acutal, km	6235	6045	5955
visible, km	6300	6100	6000
Acceleration (gravity)			
actual surface, cm/sec^2. . .	832	886	914
visible surface cm/sec^2. . .	815	870	900
Carbon dioxide (V%).	10	25	75
Molecular weight	29.6	32.0	40.0
Surface temperature, °K . . .	750	700	650
Average temperature lapse rate in troposphere, °K/km . . .	-7.84	-8.49	-9.27
Tropopause height, km	71	56	46
Stratosphere temperature, °K	194.2	225.2	224.0
Thermosphere begins, km . . .	126	115	83
Thermosphere lapse rate, °K/km	1.94	2.23	2.89

All three models were required to conform to the following well-established data:

Temperature at the top of the clouds, 234° K to 220° K

Pressure scale height at 60 km above the clouds, 6.8 ± 0.1 km

Logarithmic derivative of pressure scale height $\frac{d \ln H}{d Z}$ at 60 km above the clouds, $0.010 \pm 0.002\ \mathrm{km}^{-1}$

5.0 Near-Mars Space

Near-Mars space is defined as the region between 130 km and 17 000 km above the surface of Mars.

5.1 Meteoroid Environment

5.1.1 Model.- See paragraph 2.1.1.

5.1.2 Erosion rate.- See paragraph 2.1.2.

5.2 Radiation Environment

5.2.1 Galactic cosmic radiation.- See paragraph 2.2.1.

5.2.2 Solar high energy particle radiation.- See paragraph 2.2.2. The flux and energy of this environmental parameter at the orbit of Mars will probably be reduced from that at the Earth.

5.2.3 Solar flares.- See paragraph 2.2.3.

5.3 Gas Properties

The following gas properties of near-Mars space were calculated on a theoretical basis in the determination of the mean Mars model atmosphere. Because of uncertainties in the atmospheric parameters, some variation in the values may occur.

5.3.1 Gas pressure.- Gas pressure varies from $\approx 10^{-3}$ dyne/cm^2 at 130 km altitude to that of nearby space of $< 10^{-10}$ dyne/cm^2. Refer to the table in 5.3.3

5.3.2 Gas density.- Gas density varies from $\approx 10^{-11}$ gm/cc at 130 km altitude to that of nearby space of $< 10^{-18}$ gm/cc. Refer to the table in 5.3.3.

5.3.3 Kinetic gas temperature.- The kinetic gas temperature is $\approx 132°$ K at 130 km altitude and will probably remain constant until merging with the interplanetary gas which is at a kinetic temperature of $\approx 1.9 \times 10^{5}$° K. Refer to the following table.

Gas Properties of Near-Mars Space			
Altitude, km	Pressure, dyne/cm^2	Density, gm/cc	Temperature, °K
130	5.57×10^{-3}	1.78×10^{-11}	132.0
150	6.09×10^{-4}	1.95×10^{-12}	132.0
170	6.83×10^{-5}	2.19×10^{-13}	132.0
190	7.85×10^{-6}	2.51×10^{-14}	132.0
210	9.29×10^{-7}	2.97×10^{-15}	132.0
230	1.17×10^{-7}	3.75×10^{-16}	132.0
250	1.58×10^{-8}	5.06×10^{-17}	132.0
270	2.28×10^{-9}	7.29×10^{-18}	132.0
300	$1.4. \times 10^{-10}$	4.50×10^{-19}	132.0
Interplanetary	$< 10^{-10}$	$< 10^{-18}$	$\approx 1.9 \times 10^{5}$

5.4 Magnetic Field (Ref. 10)

Planetary: Mariner IV data indicate that the magnetic field of Mars is less than 10^{-3} that of the Earth magnetic field.

Solar: Mariner IV data indicate a strongly disordered interplanetary magnetic field lying near the plane of the solar equator. An average value of 3 gammas may be assumed. Fluctuations of one or two orders of magnitude may occur depending upon solar activity.

5.5 Radiation Properties of the Sun and Mars

5.5.1 Solar radiation.- See paragraph 2.5.1.

5.5.1.1 Visible and infrared radiation: See paragraph 2.5.1.1.

5.5.1.2 Ultraviolet and X-ray radiation: See paragraph 2.5.1.2.

5.5.1.3 Solar radiation pressure: See paragraph 2.5.1.3.

5.5.1.4 Solar wind: See paragraph 2.5.1.4.

5.5.2 Planetary radiation (refs. 15 and 22).- The total radiation from Mars consists of the sum of thermal and albedo radiation from Mars and decreases with the distance from the surface of Mars and position angle measured from the Sun-Mars line.

5.5.2.1 Thermal radiation: Varies from $\approx$ 168 watts/m^2 at 200 km to $\approx$ 3 watts/m^2 at 2×10^4 km when measured on the Sun-Mars line. The spectral distribution for thermal radiation peaks near 10 microns and follows that of a black body at a temperature of $\approx$ 280° K.

The incident thermal radiation may be found from the equation:

$$Q = FAI$$

where:

Q = incident thermal radiation flux
F = view factor
A = cross sectional area of exposed spherical surface
I = planetary thermal radiation flux

Refer to the table in 5.5.2.2.

5.5.2.2 Albedo radiation: Varies from 122 watts/m^2 at $\approx$ 200 km to $\approx$ 2 watts/m^2 at 2×10^4 km under maximum conditions (zero phase angle and normal to flux). Spectral distribution of albedo radiation expected to approximate solar spectrum. Albedo radiation will contribute about 40 percent of the total radiation from the planet upon the spacecraft if a planetary integrated albedo of 0.15 is taken. No reliable determinations of the integrated albedo of Mars are available at present. Therefore, values appearing in this section were based upon the assumption that the integrated albedo is approximated by the visual albedo. The albedo radiation is directly proportional to the planetary albedo as shown in the general equation for albedo radiation flux:

$$Q = FASa$$

where:

Q = incident albedo radiation flux
F = view factor
A = cross sectional area of exposed spherical surface
S = solar constant at the planet
a = planetary albedo

Refer to the following table.

Mars Thermal and Albedo Radiation Upon a Spherical Satellite		
Albedo = 0.15; Solar constant = 600 watts/m^2, Thermal radiation flux = 128 watts/m^2.		
Altitude, km	Thermal, watts/m^2	Albedo, watts/m^2
200	168	122
400	140	99
600	120	84
1 000	93	63
4 000	29	24
8 000	11	7
20 000	3	2

5.5.2.3 Planetary albedo:

Wavelength, microns	Albedo	Wavelength, microns	Albedo (a)
0.40	0.035	0.80	0.298
.45	.065	.90	.30
.50	.085	1.00	.298
.55	.125	1.10	.285
.60	.21	1.20	.27
.65	.25	1.3	.255
.70	.275	1.4	.24
.75	.29		

[a]Estimated.

5.5.3 Planetary radiation belts (ref. 10).- Mariner IV data indicate that Mars has no magnetically trapped radiation beyond four Mars radii.

5.6 Solar Radio Noise (Ref. 13)

Noise flux will decrease ≈ 57 percent when going from Earth vicinity to Mars vicinity. See paragraph 2.6.

6.0 Mars Atmosphere and Surface Conditions

The atmosphere of Mars is defined as the region between the surface level and 130 km $\left(10^{-11}\ gm/cm^3\right)$. Uncertainties in the atmospheric data indicate an increase or decrease by a factor of 1.4 in this height is reasonable (such as up to 175 km or down to 90 km).

6.1 Atmospheric Molecular Weight and Composition (Refs. 17 and 23 to 30)

6.1.1 Molecular weight.-

Lower density model, maximum	Mean density model, mean	Upper density model, minimum
43.45	35.1	35.85

6.1.2 Composition of assumed models by volume percentage.-

	Upper density model, percent	Mean density model, percent	Lower density model, percent
N_2	51.8	56	3.3
CO_2	48.8	44	96.7

6.1.3 Argon.- If the abundance of argon is assumed to be proportional to the surface area of the planet, the Mars atmosphere has from 0.6 to 25 percent argon by volume.

6.1.4 Oxygen.- There has been no experimental evidence to indicate there is any free molecular oxygen on Mars. Absence of O_2 in the Mars' spectra sets an upper limit of 70 cm atm for the O_2 content. If oxygen is present, it is probably a result of dissociation of CO_2 and CO at high altitudes in the atmosphere of Mars. An ozone maximum of $10^{12}/cm^3$ may occur at the surface.

6.1.5 Water.- Water has long been suspected as being the constituent of the polar caps. The most recent estimate is 14 ± 7 microns precipitable water. Previous literature values have given values from 6 microns to 350 microns water (compared to the Earth's 100 to 1000 microns).

6.1.6 Reduced gases.- Reduced gases including substituted methanes were recently discovered. (Individual mole fractions are 10^{-3}).

6.2 Model Atmosphere Structure (Ref. 31)

Three model atmospheres are presented in describing the structure of the Mars atmosphere. The values given are tabulated in terms of the particular model (upper, mean, and lower density models) and in terms of the maximum, mean, and minimum values for the quantities of interest. Thus a consistent set of quantities for any one of the three model atmospheres may be obtained from the tables by following the "model" nomenclature, while the variation in a given quantity may be obtained by following the headings "maximum", "mean", and "minimum".

The parameters used for construction of these model atmospheres are given in paragraphs 6.1 and 6.13.

6.2.1 Atmospheric pressure.-

Z, km	Upper density model, max., mb	Mean density model, mean, mb	Lower density model, min., mb
0	10.0	8.0	5.0
5	7.57	5.59	3.04
10	5.63	3.77	1.73
20	2.92	1.51	.442
30	1.40	.515	.103
40	.620	.162	2.27×10^{-2}
50	.260	5.04×10^{-2}	4.62×10^{-3}
75	2.68×10^{-2}	2.80×10^{-3}	6.01×10^{-5}
100	2.83×10^{-3}	1.62×10^{-4}	3.96×10^{-7}
150	3.52×10^{-5}	6.09×10^{-7}	
200	1.50×10^{-6}	2.69×10^{-9}	
300	3.49×10^{-8}		

6.2.2 Atmospheric temperature.-

Z, km	Upper density model, max., °K	Mean density model, mean, °K	Lower density model, min., °K
0	300.0	230.0	210.0
5	281.2	210.5	185.0
10	262.4	191.1	160.0
20	228.8	156.5	136.2
30	204.9	137.5	129.8
40	186.8	132.0	123.4
50	176.3	132.0	117.0
75	171.0	132.0	101.0
100	171.0	132.0	85.0
150	175.0	132.0	85.0
200	300.0	132.0	
300	410.0		

6.2.3 Atmospheric density.-

Z, km	Upper density model, max., gm/cm^3	Mean density model, mean, gm/cm^3	Lower density model, min., gm/cm^3
0	1.44×10^{-5}	1.47×10^{-5}	1.24×10^{-5}
5	1.16×10^{-5}	1.12×10^{-5}	8.60×10^{-6}
10	9.25×10^{-6}	8.33×10^{-6}	5.64×10^{-6}
20	5.50×10^{-6}	4.08×10^{-6}	1.70×10^{-6}
30	2.94×10^{-6}	1.58×10^{-6}	4.16×10^{-7}
40	1.43×10^{-6}	5.19×10^{-7}	9.60×10^{-8}
50	6.35×10^{-7}	1.61×10^{-7}	2.07×10^{-8}
75	6.76×10^{-8}	8.95×10^{-9}	3.11×10^{-10}
100	7.15×10^{-9}	5.17×10^{-10}	2.44×10^{-12}
150	8.68×10^{-11}	1.95×10^{-12}	
200	2.16×10^{-12}	8.59×10^{-15}	
300	3.67×10^{-14}		

6.2.4 Atmospheric mean free path.-

Z, km	Lower density model, max., cm	Mean density model, mean, cm	Upper density model, min., cm
0	9.0×10^{-4}	6.5×10^{-4}	6.7×10^{-4}
5	1.2×10^{-3}	8.1×10^{-4}	7.9×10^{-4}
10	1.9×10^{-3}	1.1×10^{-3}	1.0×10^{-3}
20	6.2×10^{-3}	2.2×10^{-3}	1.7×10^{-3}
30	2.5×10^{-2}	5.7×10^{-3}	3.1×10^{-3}
40	1.1×10^{-1}	1.7×10^{-2}	6.4×10^{-3}
50	5.1×10^{-1}	5.6×10^{-2}	1.5×10^{-2}
75	3.4×10^{1}	1.0	1.4×10^{-1}
100	4.3×10^{3}	1.8×10^{1}	1.3
150	2.0×10^{8}	4.7×10^{3}	1.1×10^{2}
200		1.1×10^{6}	4.3×10^{3}
300			2.5×10^{5}

6.2.5 Coefficient of viscosity.-

Z, km	Upper density model, max., kg m^{-1}-sec^{-1}	Mean density model, mean, kg m^{-1}-sec^{-1}	Lower density model, min., kg m^{-1}-sec^{-1}
0	1.70×10^{-5}	1.26×10^{-5}	1.01×10^{-5}
5	1.60×10^{-5}	1.17×10^{-5}	$.90 \times 10^{-5}$
10	1.47×10^{-5}	1.06×10^{-5}	$.78 \times 10^{-5}$
20	1.26×10^{-5}	$.88 \times 10^{-5}$	$.68 \times 10^{-5}$
30	1.12×10^{-5}	$.79 \times 10^{-5}$	$.65 \times 10^{-5}$
40	1.02×10^{-5}	$.76 \times 10^{-5}$	$.62 \times 10^{-5}$
50	$.97 \times 10^{-5}$	$.76 \times 10^{-5}$	$.59 \times 10^{-5}$
75	$.94 \times 10^{-5}$	$.76 \times 10^{-5}$	$.53 \times 10^{-5}$
100	$.94 \times 10^{-5}$	$.76 \times 10^{-5}$	$.46 \times 10^{-5}$
150	$.96 \times 10^{-5}$	$.76 \times 10^{-5}$	$.46 \times 10^{-5}$
200	1.73×10^{-5}	$.76 \times 10^{-5}$	
300	2.67×10^{-5}		

6.2.6 Pressure scale height.-

Z, km	Upper density model, max., km	Mean density model, mean, km	Lower density model, min., km
0	18.3	14.6	10.5
5	17.4	13.3	9.5
10	16.3	12.1	8.2
20	14.3	10.0	7.0
30	12.9	8.8	6.7
40	11.8	8.5	6.4
50	11.2	8.6	6.1
75	11.0	8.7	5.4
100	11.2	8.8	4.6
150	11.8	9.1	4.7
200	20.8	9.3	
300	30.0		

6.2.7 Atmospheric speed of sound.-

Z, km	Upper density model, max., m/sec	Mean density model, mean, m/sec	Lower density model, min., m/sec
0	308	273.0	232
5	300	261.0	220
10	290	249.0	205
20	271	225.0	189
30	256	211.0	184
40	245	207.0	180
50	238	207.0	175
75	234	207.0	163
100	234	207.0	149
150	237	207.0	149
200	310	207.0	
300	362		

6.2.8 Atmospheric number density.-

Z, km	Upper density model, max., cm^{-3}	Mean density model, mean, cm^{-3}	Lower density model, min., cm^{-3}
0	2.3×10^{17}	2.5×10^{17}	1.6×10^{17}
5	2.0×10^{17}	1.9×10^{17}	1.2×10^{17}
10	1.6×10^{17}	1.4×10^{17}	7.8×10^{16}
20	9.2×10^{16}	7.0×10^{16}	2.4×10^{16}
30	4.9×10^{16}	2.7×10^{16}	5.8×10^{15}
40	2.4×10^{16}	8.9×10^{15}	1.3×10^{15}
50	1.1×10^{16}	2.8×10^{15}	2.9×10^{14}
75	1.1×10^{15}	1.5×10^{14}	4.3×10^{12}
100	1.2×10^{14}	8.9×10^{12}	3.4×10^{10}
150	1.5×10^{12}	3.3×10^{10}	7.4×10^{5}
200	3.6×10^{10}	1.5×10^{8}	
300	6.2×10^{8}		

6.2.9 Atmospheric density scale height.-

Z, km	Upper density model, max., km	Mean density model, mean, km	Lower density model, min., km
0	23.9	19.2	14.0
5	22.7	17.7	12.7
10	21.3	16.1	11.0
20	16.8	11.9	7.3
30	15.2	9.2	7.0
40	13.0	8.5	6.7
50	11.9	8.6	6.4
75	11.0	8.7	5.6
100	11.2	8.8	4.8
150	11.5	9.1	4.7
200	17.7	9.3	
300	29.2		

6.2.10 Atmospheric columnar mass above a given altitude.-

Z, km	Upper density model, max., gm/cm^2	Mean density model, mean, gm/cm^2	Lower density model, min., gm/cm^2
0	26.9	21.5	13.4
5	21.6	16.2	9.07
10	16.2	11.1	5.25
15	11.9	7.3	3.34
20	8.5	4.6	1.40
25	6.0	2.7	.70
30	4.1	1.6	.30
35	2.8	.9	.20
40	1.9	.5	.10
45	1.2	.3	.0
50	.8	.2	.0
55	.5	.1	.0
60	.3	.1	.0
65	.2	.1	.0
70	.1	.0	.0

6.2.10.1 Columnar mass for Earth above a given altitude: See paragraph 4.2.10.1.

6.2.11 Ultraviolet radiation reaching the surface through the atmosphere.- Between 2000 and 3000 angstrom units, approximately 90 percent of the direct solar radiation should reach the surface.

6.3 Atmospheric Winds for Mars (Refs. 32 and 33)

The maximum winds in the atmosphere will occur near the tropopause (20 to 30 km). However the wind speed of storm systems (average 50 m/sec) may exceed the winds at the tropopause. Peak storm winds may exceed 100 m/sec.

Since the meridional temperature gradient is much larger than the zonal (west-east) temperature gradient on Mars, according to the thermal wind equation the west-east winds are much stronger than the meridional winds (just as on the Earth).

6.3.1 Theoretical maximum winds for Mars.- The following data were derived theoretically from temperatures of the surface of Mars using the thermal wind equation.

6.3.1.1 Maximum magnitude of winds for summer (Northern Hemisphere):

Z, km	Southern Hemisphere U, m/sec		Northern Hemisphere U, m/sec	
	U(0) = 0[a]	U(0) = 25[a]	U(0) = 0[a]	U(0) = 25[a]
0	0	25	0	25
5	10	35	7.5	32.5
10	20	45	15.	40
15	30	55	22.5	47.5
20	40	65	30	55
24	48	73	36	61

6.3.1.2 Maximum magnitude of winds for spring or fall:

Z, km	Southern Hemisphere U, m/sec		Northern Hemisphere U, m/sec	
	U(0) = 0[a]	U(0) = 25[a]	U(0) = 0[a]	U(0) = 25[a]
0	0	25	0	25
5	15	40	15	40
10	30	55	30	55
15	45	70	45	70
20	60	85	60	85
24	72	97	72	97

6.3.1.3 Maximum magnitude of winds for winter (Northern Hemisphere):

Z, km	Southern Hemisphere U, m/sec		Northern Hemisphere U, m/sec	
	U(0) = 0[a]	U(0) = 25[a]	U(0) = 0[a]	U(0) = 25[a]
0	0	25	0	25
5	4	29	20	45
10	8	33	40	65
15	12	37	60	85
20	16	41	80	105
24	20	45	96	121

[a]U(0) indicates the wind value assumed at the surface.

6.4 Wind Shear

These wind shear values were calculated theoretically using the thermal wind equation. Wind shears higher than these values can occur near frontal systems, squall lines, near the jet axis, or near low level jet streams on the night side (if they exist on Mars). The magnitude of the deviation is not now known.

6.4.1 Summer (Northern Hemisphere).-

Southern Hemisphere	Northern Hemisphere
$\frac{du}{dz}, \frac{m/sec}{km}$	$\frac{du}{dz}, \frac{m/sec}{km}$
2	1.5

6.4.2 Spring and fall.-

Southern Hemisphere	Northern Hemisphere
$\frac{du}{dz}, \frac{m/sec}{km}$	$\frac{du}{dz}, \frac{m/sec}{km}$
3	3

6.4.3 Winter (Northern Hemisphere).-

Southern Hemisphere	Northern Hemisphere
$\frac{du}{dz}, \frac{m/sec}{km}$	$\frac{du}{dz}, \frac{m/sec}{km}$
0.8	4

6.5 Clouds in the Atmosphere

6.5.1 Yellow clouds (refs. 33 to 39).- Yellow clouds, which are visible in red, but not in blue light, appear after a seasonal increase in insolation. They usually form as small areas and grow larger with time, sometimes obscuring the entire visible disk. Their size ranges from near 100 km (or just above the resolution limit) to approximately 300 000 square miles. They usually last one or two nights, and are most prevalent on the morning terminator. The daylight occurrences may be due to dust devils in the atmosphere. They are predominant at heliocentric longitudes 270° and 30°. The morning prevalence of these clouds may indicate the existence of high winds during the night. The particles composing the yellow clouds have a density near 3 gm/cm^3 and are 1 to 20 microns in size and possibly larger. They occur most frequently at 5.0 to 9.0 km.

6.5.2 Blue clouds (refs. 34 to 36, 40, and 41).- Blue clouds, which are visible in blue, but vanish in red light, appear to be thin "cirrus like" clouds. Polarization measurements indicate that they may be composed of transparent droplets near 2 microns in diameter. Blue clouds are most prevalent near the morning and evening terminators, and also appear to have some geographical preference (e.g., Tharsis, and the polar regions). They occur most frequently from 15 to 25 km, and may occur up to 100 km in the atmosphere.

6.5.3 White clouds (refs. 34, 35, and 42).- White clouds are visible in both yellow and blue light. Experimental evidence indicates that the polarization of the white clouds is identical with that of ice crystals near 1 micron in size. They occur predominantly over the poles and certain geographical areas. Afternoon white clouds are observed over the areas of Southern Tharsis, Phoenicis Lacus, and Arsia Silva. They occur at altitudes ranging from 15 to 50 km and are most prevalent after a seasonal increase in insolation. Nix Olympica and the Condor "ranges" appear to have persistent clouds of this variety nearby.

6.5.4 Blue haze (refs. 34, 35, and 40).- In blue light, Mars usually presents a hazy appearance, such that the surface detail is not visible. However, near favorable oppositions, clearings in this haze are observed which allow the surface features to be seen at wavelengths less than 4500 Å. To date no satisfactory explanation has been given for the blue haze. Some of the more realistic theories are:

(1) CO_2 clouds

(2) water-ice clouds

(3) selective absorbance

(4) scattering phenomenon

The blue haze is reported to occur somewhere between 5 and 200 km.

6.6 Micrometeoroid Environment

See paragraph 4.6.

6.7 Magnetic Field of Mars

See paragraph 5.4.

6.8 Atmospheric Circulation (Refs. 18 and 43)

6.8.1 Early fall and late spring.- During fall and spring the atmospheric fluid ascends at the equator and descends at the poles. Since angular momentum is conserved, the fluid near the surface spirals away from the pole and the fluid near the tropopause spirals in toward the pole. This is known as the symmetric regime.

6.8.2 Winter.- As winter approaches the circulation develops waves with low pressure systems being poleward of 45° and high pressure being on the equator side of 45°. This results in west winds in the mid-latitudes and east winds at the equator and near the pole. In the middle and upper troposphere west winds will be predominant for both the mid-latitudes and the polar regions. It is uncertain if this circulation regime breaks down into the symmetric regime late in winter or continues to have these westerly waves until spring.

6.8.3 Summer.- During summer there will be a reversed symmetric circulation, that later develops easterly waves. East winds will be predominant in the middle and upper troposphere for the middle and high latitudes.

6.9 Ionosphere (Refs. 24 and 44 to 48)

Mariner IV data have three possible interpretations:

(1) that the ions are mostly O^+ (F2 Model) and the peak electron concentration (10^6 cm^{-3}) occurs at a neutral concentration of 10^9 cm^{-3}

(2) that the ions are mostly O_2^+ (E Model) and the peak electron concentration (10^5 cm^{-3}) occurs at a neutral concentration of 5×10^{10} cm^{-3}

(3) that CO_2^+ is predominant (F1 Model)

6.10 Albedo

See paragraph 5.5.2.3.

6.11 Surface Features, Terrain, and Composition of the Surface (Refs. 35 and 49 to 59)

To the naked eye Mars appears reddish yellow, due to two-thirds of the surface being covered with "desert like" areas. In a telescope it is possible to see dark areas of a grayish green tint. These areas are called "maria" and are more prominent in the Southern Hemisphere and often appear to be connected by "canals." Mariner IV pictures suggest that the visible surface is 300 to 800 million years old.

6.11.1 Surface features.-

6.11.1.1 Southern Hemisphere: The darkest maria lie in a band located parallel to the equator from the equator southward to 30° S. South of this lies a band of reddish "desert" that extends to 55° S. The southern polar cap extends to 60° S at its maximum. Due to the relation of the tilt of Mars to the orbital elements, the Southern Hemisphere has a long "cold" winter and a short "hot" summer. This results in the Southern Hemisphere having a more extensive and faster melting polar cap than the Northern Hemisphere.

6.11.1.2 Northern Hemisphere: The Northern Hemisphere is predominantly desert like, with little maria being visible. No band like appearance is visible as in the Southern Hemisphere and its polar cap is not as extensive (65° N).

6.11.2 Terrain and composition of the surface.-

6.11.2.1 Deserts: These bright areas (continents) are orange, yellow, or reddish in color and occupy 70 percent of the area of the planet. They have an albedo of 0.15 to 0.20. Polarimetric observations indicate that the properties of the "top soil" in the deserts and maria are similar. Meteorite impact has produced a layer of dust and unconsolidated rubble. The particle size will probably be very small due to the wide diurnal temperature variation and eons of wind erosion. Particles 10^{-3} cm in radius are swept into the atmosphere where they remain for about 10 days. Erosion rates are 30 times slower than in terrestrial deserts and 70 times faster than micrometeorite erosion on the Moon. The possible composition of these areas may be limonite ($Fe_2O_3 \cdot nH_2O$), volcanic ash, rhyolitic felsite, and meteoritic products such as Ni, Fe, SiO_2, MgO, and FeO.

6.11.2.2 Craters and mountains: The craters seen in the Mariner IV photographs closely resemble the size and distribution of craters on the highlands of the Moon. They have rims about 100 meters high, depths of several hundred meters, and diameters ranging from 4 to 170 km. The crater walls have slopes up to about 10°. It is estimated that there are 10 000 craters on the entire surface. If mountains are present, they are probably no higher that 2.5 to 6.0 km. It is believed that frost covered peaks appeared in picture no. 14 taken from Mariner IV. Syrtis Major and Moeris Lacus may have elevations of 10 to 20 km.

6.11.2.3 Maria: The maria cover about 27 percent of the surface and appear gray with a greenish or bluish tint. The daytime surface temperature is about 8° C higher than that of the deserts, and the surface is covered with a dusty unconsolidated top layer which was probably produced by meteorite impact. After these areas are covered by a dust storm, a dark color results, and their recuperative ability after the subjection is notable. For a long time it has been assumed that these conditions could possibly be caused by plant life. It is generally believed that the maria are low, humid (relatively) areas, where plant life may exist. Eighty-nine craters are shown in pictures 7 to 14 taken by Mariner IV which include portions of Mare Sireuum and Mare Cimmerium. It is believed that frost can be seen in frames 14 and 15.

6.12 Surface Temperatures (Refs. 23 and 60)

6.12.1 Diurnal change.- Temperature changes from 210° K at 0600 local time to 313° K at 1300 local time.

6.12.2 Winter (Northern Hemisphere).-

Latitude, deg	Average temperature along noon meridian, °K
75 S	243
60	254
45	264
30	272
15	273
0	270
15 N	261
30	250
45	238
60	227

6.12.3 Spring (Northern Hemisphere).-

Latitude, deg	Average temperature along noon meridian, °K
75 S	225
60	239
45	251
30	262
15	270
0	275
15 N	275
30	272
45	265
60	255

6.12.4 Summer (Northern Hemisphere).-

Latitude, deg	Average temperature along noon meridian, °K
75 S	no data
60	no data
[a]55	no data
45	no data
30	no data
15	275
0	278
15 N	282
30	284
45	286
60	288

[a]Mariner IV gave 210° K at latitude 55° S late in the afternoon.

6.12.5 Fall (Northern Hemisphere).-

Latitude, deg	Average temperature along noon meridian, °K
75	240
60	248
45	249
30	242
15	235
0	238
15 N	239
30	231
45	220
60	no data

6.13 Construction Parameters for the Model Atmospheres (Refs. 23 to 26, and 61 and 62)

	Upper density model	Mean density model	Lower density model
Acceleration of gravity	375 cm/sec^2	375 cm/sec^2	375 cm/sec^2
Average radius of Mars[a]	3381 km	3381 km	3381 km
Tropopause altitude	17 km	3 km	14 km
Troposphere dT/dz	-3.764 °K/km	-3.89 °K/km	-5.00 °K/km
Tropopause temperature	236° K	218.33 °K	140.0 °K
Stratopause altitude	140 km	140 km	100 km
Stratosphere dT/dz	17-31 km -2.392 °K/km	3-10 km -2.619 °K/km	-.64 °K/km
	31-36 km -2.0 °K/km	10-26 km -1.563 °K/km	
	36-43 km -1.428 °K/km	26-40 km -.893 °K/km	
	43-56 km -0.884 °K/km	40-50 km -0.4 °K/km	
	56-140 km 0.0 °K/km	50-140 km 0.0 °K/km	
Stratopause temperature	171.0 °K	158.5 °K	85.0 °K
Thermopause altitude	300 km	300 km	- -

[a]Mariner IV gave 3384 ± 3 km at entrance occultation 50.5° S latitude and 3379 ± 4 km at exit, 60° N latitude.

6.14 Planetary Satellites (Refs. 12, 63, and 64)

Mars has two known satellites named Phobos and Deimos. Phobos, the larger of the two, has a period of revolution around Mars which is about one-third of the period of rotation of Mars on its axis. As the result, Phobos would appear to be in retrograde motion as seen from the surface of Mars although actually it is not. The effect produced is the rising of Phobos in the west, an eastward motion across the sky, eventually setting in the east. This motion is apparently contrary (retrograde) to the apparent diurnal motion of the stars from east to west which is produced by the rotation of Mars on its axis. Deimos is very nearly a synchronous satellite. Its period of revolution around Mars is only slightly longer than the period of rotation of Mars on its axis. The effect produced is the conventional rising of Deimos in the east, a very slow westward motion across the sky, eventually setting in the west. Both satellites are small. In the sky of Mars, Phobos would appear to be about one-quarter the size of our full moon, and Deimos would appear like a bright star. No other satellites of Mars have been detected in search programs. However, objects less than 1 mile in diameter would be beyond detection.

6.14.1

Phobos.-	
Diameter, km	12 to 19
Mean distance from center of Mars, km	9350
Orbital inclination to equator of Mars, deg	1.1
Orbital inclination to orbit of Mars, deg	27.5
Period of revolution (synodic), hr:min:sec	7:39:13
Eccentricity	0.0170

6.14.2

Deimos.-	
Diameter, km	6 to 10
Mean distance from center of Mars, km	23 400
Orbital inclination to equator of Mars, deg	0.9 to 2.7
Orbital inclination to orbit of Mars, deg	27.5
Period of revolution (synodic), hr:min:sec	30:17:17
Eccentricity	0.0031

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